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SOUTH DURHAM WRF ODOR CONTROL REHABILITATION

Date: October 2015

To: City of Durham

From: Hazen and Sawyer, PC

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1.0 Background

During the PER stage of the South Durham WRF FY14 Improvements project, the City decided to include odor control as part of the Phase 2 construction. The cost to rehabilitate the three existing odor scrubbers and the operational cost and maintenance associated with chemical scrubbers was higher than anticipated, which led to the evaluation of alternate odor control technologies such as biofilters, bio-trickling filters, and carbon scrubbers. In order to fully quantify the costs of each alternative and provide a sound odor control design, Hazen and Sawyer performed sampling and monitoring to gather hydrogen sulfide and odor concentration data, which is presented in this technical memorandum.

1.1 Existing Chemical Odor Scrubbers

The South Durham Water Reclamation Facility (SDWRF) has three existing chemical odor scrubbers. Odor Scrubber No. 1 serves the belt filter press and blend tanks and has a capacity of 28,250 cubic feet per minute (cfm).

The design basis for airflows for each process unit for Scrubber No. 1 is shown in **Table 1-1** below.

Table 1-1: Existing Odor Scrubber No. 1 Equipment and Capacities		
Equipment	**Airflow (cfm)**	**Approximate Air Changes per Hour**
Belt Filter Press Building	24,000	12-14
Blend Tanks	4,250	12 per tank
Total Capacity	**28,250**	

Scrubber No. 2 has a capacity of 14,250 cfm and serves the existing preliminary treatment facility, scum concentrator building, scum pump wet well, primary settling tank effluent channel, and primary settling tanks. **Table 1-2** below lists the design airflow, and approximate number of air changes per hour per process area.

Table 1-2: Existing Odor Scrubber No. 2 Equipment and Capacities		
Equipment	**Airflow (cfm)**	**Approximate Air Changes per Hour**
Primary Settling Tanks	4,800	10-12
Primary Settling Tank Effluent Channel	1,300	12
Scum Pump Wet Well	50	10-12
Scum Concentrator Building	1,800	11-12
Preliminary Treatment Facilities	6,300	12
Total Capacity	**14,250**	

Scrubber No. 3 has a capacity of 3,000 cfm and serves the influent pump station wet well, screening conveyor and hood, and influent manhole. **Table 1-3** below lists the air flow and air changes per hour for each process area.

Table 1-3: Existing Odor Scrubber No. 3 Equipment and Capacities		
Equipment	**Airflow (cfm)**	**Approximate Air Changes per Hour**
Influent Pump Station Wet Well	2,700	12-18
Screening Conveyor and Hood	100	12-15
Influent Splitter Box	200	12-15
Total Capacity	**3,000**	

1.2 Technical Memorandum Scope

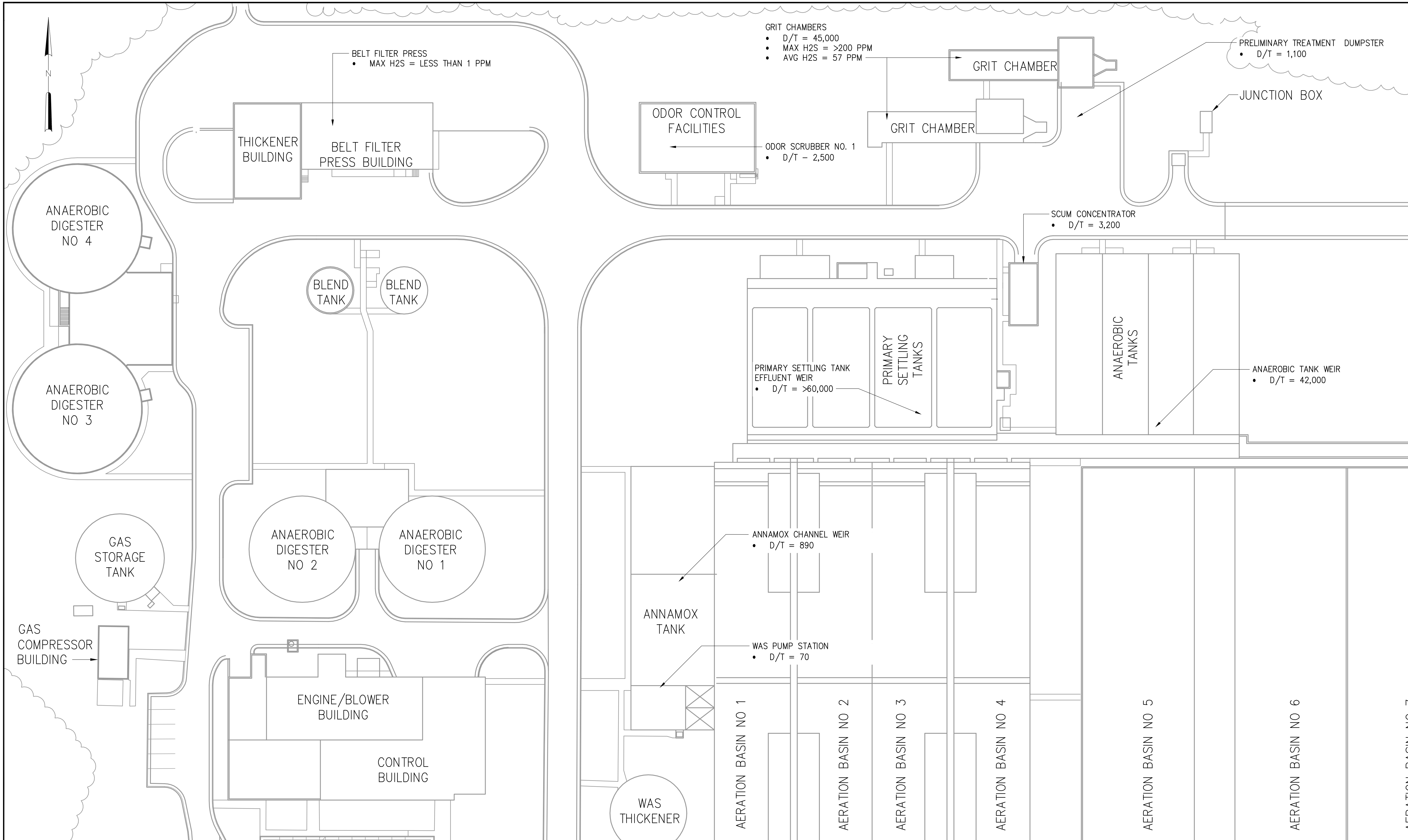
The purpose of this Technical Memorandum is to evaluate odor control alternatives for process areas currently scrubbed, and to recommend alternatives for inclusion into the Phase 2 FY14 WRF Improvements Project. Airflow requirements and technology alternatives for the Phase 1 Preliminary Treatment Facility will be evaluated, and design and construction of the odor control facility for the PTF will be completed with the Phase 1 WRF Improvements project.

2.0 Sampling and Identification of Potential Odor Sources

After reviewing the site plans and future improvements and expansion for the SDWRF, sampling sites and potential odor sources were determined. **Figures 2-1** and **2-2** illustrate the locations at which samples were taken at the SDWRF, which are identified in **Table 2-1**.

Table 2-1: SDWRF Odor Sampling Locations		
Sample Site	**Sensory Sample**	**Odalog Sample**
Influent Manhole	X	X
Influent Pump Station Wet Well	X	X
Scum Concentrator Building	X	
Grit Chamber	X	X
Gravity Belt Thickener		X
Preliminary Treatment Facility	X	
Primary Settling Tanks Effluent Weirs	X	
Annamox Tank Channel	X	
WAS Pump Station	X	
Odor Scrubber 1 Intake	X	
Anaerobic Tank Overflow	X	

Two different types of samples were taken at the SDWRF, sensory and diurnal hydrogen sulfide monitoring. The sensory samples were tested for dilution to threshold and recognition threshold, which are a surrogate for odor concentration. Hydrogen sulfide analysis was also conducted on these samples. The sensory samples were shipped via overnight air to the St. Croix Sensory Inc. laboratory in Lake Elmo, Minnesota. Sensory analyses followed ASTM E679 and ASTM E544 methodology and were analyzed within 24 hours of collection.



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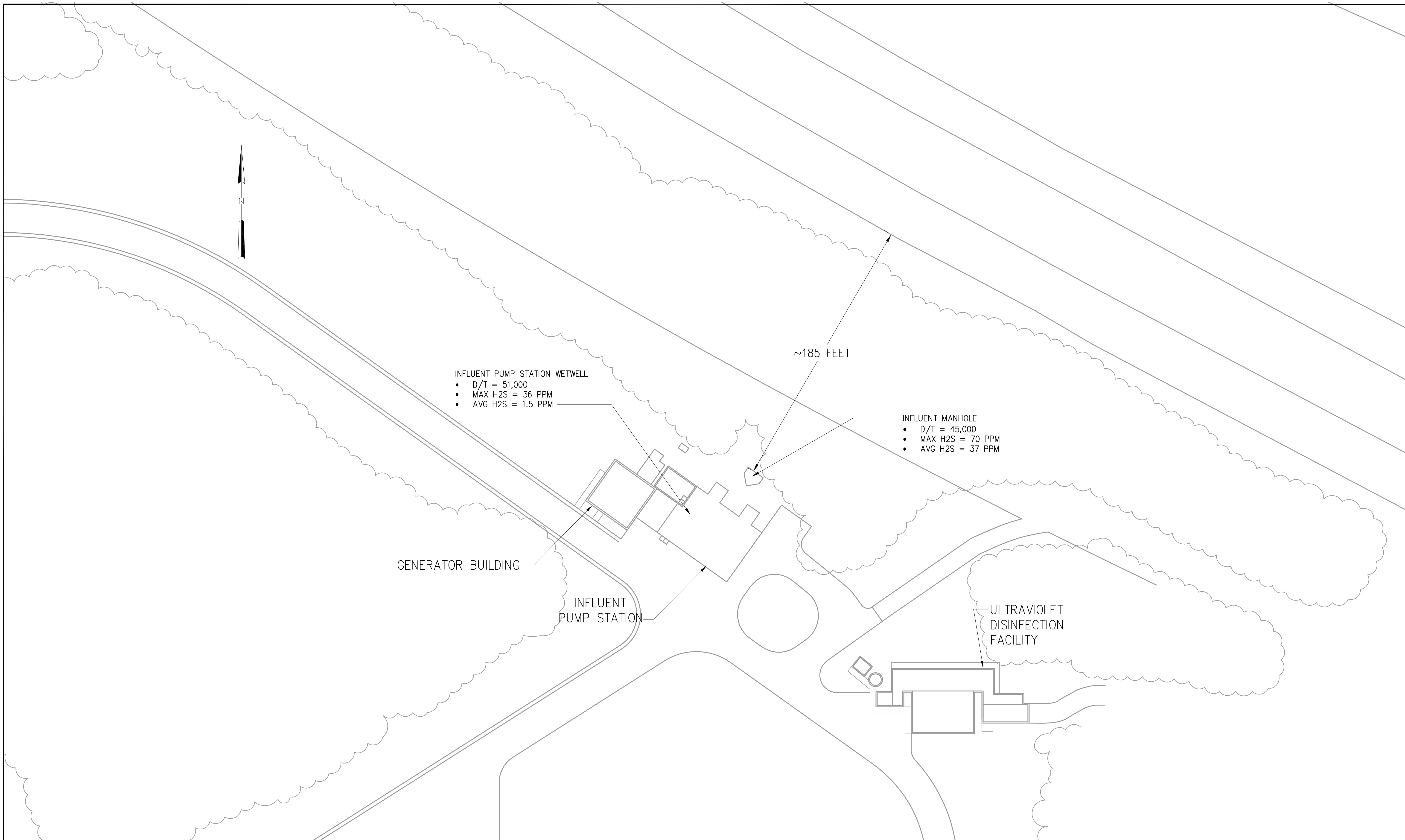
CITY OF DURHAM, NORTH CAROLINA
DEPARTMENT OF WATER MANAGEMENT

SOUTH DURHAM WATER RECLAMATION FACILITY

FIGURE 2-1
2015 ODOR STUDY

SAMPLING LOCATIONS & RESULTS



Hazen 4011 WestChase Boulevard, Suite 500 Raleigh, North Carolina 27607 License No. : C-0381	CITY OF DURHAM, NORTH CAROLINA DEPARTMENT OF WATER MANAGEMENT SOUTH DURHAM WATER RECLAMATION FACILITY	FIGURE 2-2 2015 ODOR STUDY SAMPLING LOCATIONS & RESULTS

The dilution to threshold (D/T) determines the number of dilutions at which 50 percent of a human panel can identify the presence of an odor without being able to identify the source. The higher the D/T value, the more dilutions possible to the threshold and the stronger the odor source. The recognition threshold (R/T) determines the number of dilutions at which 50 percent of a human panel can identify an odor. Typically, the D/T is higher than the R/T, indicating that an odor may be detectable at more dilute concentrations than at which it can be identified.

Upon receipt of the samples by St. Croix laboratories, all samples were evaluated within 24 hours of collection, which is a requirement established by ASTM protocols. For the Threshold Determination, a 4-member panel evaluated the samples using an olfactometer. All panel members had been previously screened to determine their sensory sensitivity. The majority of the panel members had what was considered average sensitivity. The panel also included members with less than and greater than average sensitivity. Each member "sniffs" three sniffing tubes. Only one of the ports contains the odor and the remaining ports are odor free. The method used is considered the "forced choice" method whereas each member is forced to choose which port has the odorous sample. The D/T does not consider any specific odorants such as hydrogen sulfide, but provides a composite analysis of each specific odor.

The diurnal hydrogen sulfide monitoring was conducted using an Odalogger, which monitors hydrogen sulfide and temperature in a given area. The unit samples several times a minute and measures the hydrogen sulfide concentrations in a given area. Although not all odors are comprised primarily of hydrogen sulfide, hydrogen sulfide monitoring provides validation that the long-term odor trends are consistent with the odors identified in the grab samples collected in the sampling described above.

Sampling at the SDWRF was performed in August 2015.

2.1 Sampling Results

The results of the sampling for the SDWRF are presented in **Table 2-2**. The complete data reports are available in **Appendix A** of this document.

Table 2-2: SDWRF Odor Control Sampling Summary

Sample Site	D/t	R/t	H_2S from Sensory Sample (ppm)	Max H_2S from Odalog (ppm)	Average H_2S from Odalog (ppm)
Influent Splitter Manhole	45,000	26,000	11.9	70	37
Influent Pump Station Wet Well	51,000	29,000	21.2	36.0	1.5
Scum Concentrator Building	3,200	2,200	0.02	70	0.5
Grit Chamber	45,000	29,000	44.1	331	56.5
Gravity Belt Thickener				0.0	0.0
Preliminary Treatment Facility	1,100	700	0.004		
Primary Settling Tanks Effluent Weirs	>60,000	>60,000	55.8		
Annamox Tank Channel	890	500	0.075		
WAS Pump Station	70	40	0.046		
Odor Scrubber 1 Intake	2,500	1,500	0.24		
Anaerobic Tank Overflow	42,000	27,000	1.5		

The data in **Table 2-2** indicates that higher hydrogen sulfide concentrations correlate to higher D/T and R/T. The highest odors were measured at the influent splitter manhole, influent pump station wet well, grit chamber, primary settling tank effluent weirs and anaerobic tank overflow.

3.0 Odor Technology Overview

This section describes the vapor phase treatment systems that will be evaluated in this technical memorandum.

3.1 Chemical Scrubbers

Chemical scrubbers, also known as packed bed scrubbers, are widely used and have a long performance history. They can be implemented individually or in combination with other odor control technologies. Packed bed scrubbers utilize chemical reactions to remove odorous compounds. For sulfur related compounds, alkaline scrubbing can be employed; the traditional chemicals for alkaline scrubbing are sodium hydroxide and sodium hypochlorite, although oxidants such as ozone and hydrogen peroxide can also be used.

Packed bed scrubbers rely on recirculation of chemicals and make-up water to provide the retention time required for adequate gas – liquid transfer. The foul air flows upward through media while recirculated chemical solution flows downward. The media is typically small plastic spheres designed to provide optimal surface area for gas-liquid mass transfer. As the recirculated liquid comes in contact with the foul air, the contaminants in the air are transferred to the liquid. Recirculated liquid is continuously wasted and replenished with fresh make-up water to prevent saturation of sulfides.

An advantage of wet scrubbing is that the percent removals achieved can be very high. Hydrogen sulfide removal rates above 99% are not uncommon. Another advantage of wet scrubbing is the controlled process which directly responds to changes in hydrogen sulfide concentrations. Chemical addition is based on incoming airflow conditions. The disadvantages of chemical scrubbers are the cost of the chemicals required and the additional maintenance of having chemicals onsite.

Chemical scrubbers can be installed in stages depending on the percent removal required. The number of stages in a chemical scrubber is dependent upon expected removal efficiency and hydrogen sulfide concentration. For a one stage scrubber, sodium hydroxide (caustic) and sodium hypochlorite are added in the same stage. The high pH created in the recirculation liquid converts hydrogen sulfide gas to sodium sulfide and water. If the pH of the recirculated liquid drops below 10, the reaction can be reversed, and hydrogen sulfide will be regenerated. In order to keep the sulfide ion from reforming hydrogen sulfide gas, sodium hypochlorite is added. Sodium hypochlorite reacts with the sulfide ion to convert it to sulfite, which remains dissolved in water.

A schematic of a typical one stage packed bed chemical scrubber is shown in **Figure 3-1**.

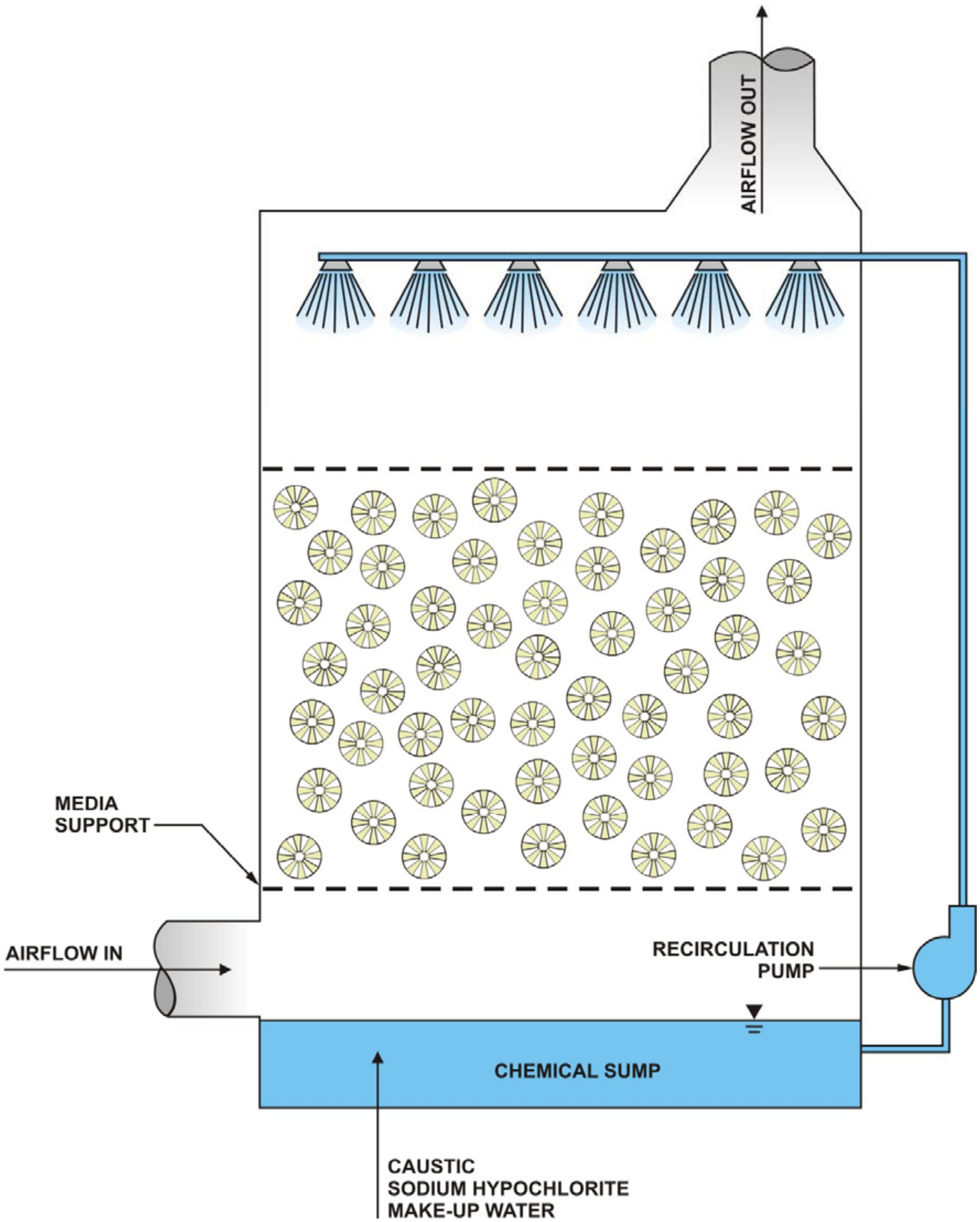


Figure 3-1: One-Stage Packed Bed Chemical Scrubber

In a multi-stage scrubber, foul air passes through a series of packed bed stages. The foul air enters the first stage in which the scrubbing liquid typically consists of make-up water and caustic. The caustic removes approximately 80 to 90 percent of the hydrogen sulfide in the foul air by converting it to sodium sulfide. Subsequent stages consist of co-current or counter-current air flow passing through the packed media. In the intermediate stages, the scrubbing solution usually consists of caustic, sodium hypochlorite and make-up water. The scrubbing liquid in the last stage of a multi-stage scrubber consists of water and sodium hypochlorite, which removes the remainder of the hydrogen sulfide as well as the organics in the foul air. The stage with primarily sodium hypochlorite is typically used as a polishing step, which provides additional hydrogen sulfide removal and prevents the sulfide from coming out of solution. Chemical scrubbers are also very effective in removing total odor, not just hydrogen sulfide. A properly designed and maintained chemical scrubber is capable of removing 99% of total odor, in addition to hydrogen sulfide.

A schematic of a typical multi-stage scrubber is shown in **Figure 3-2**.

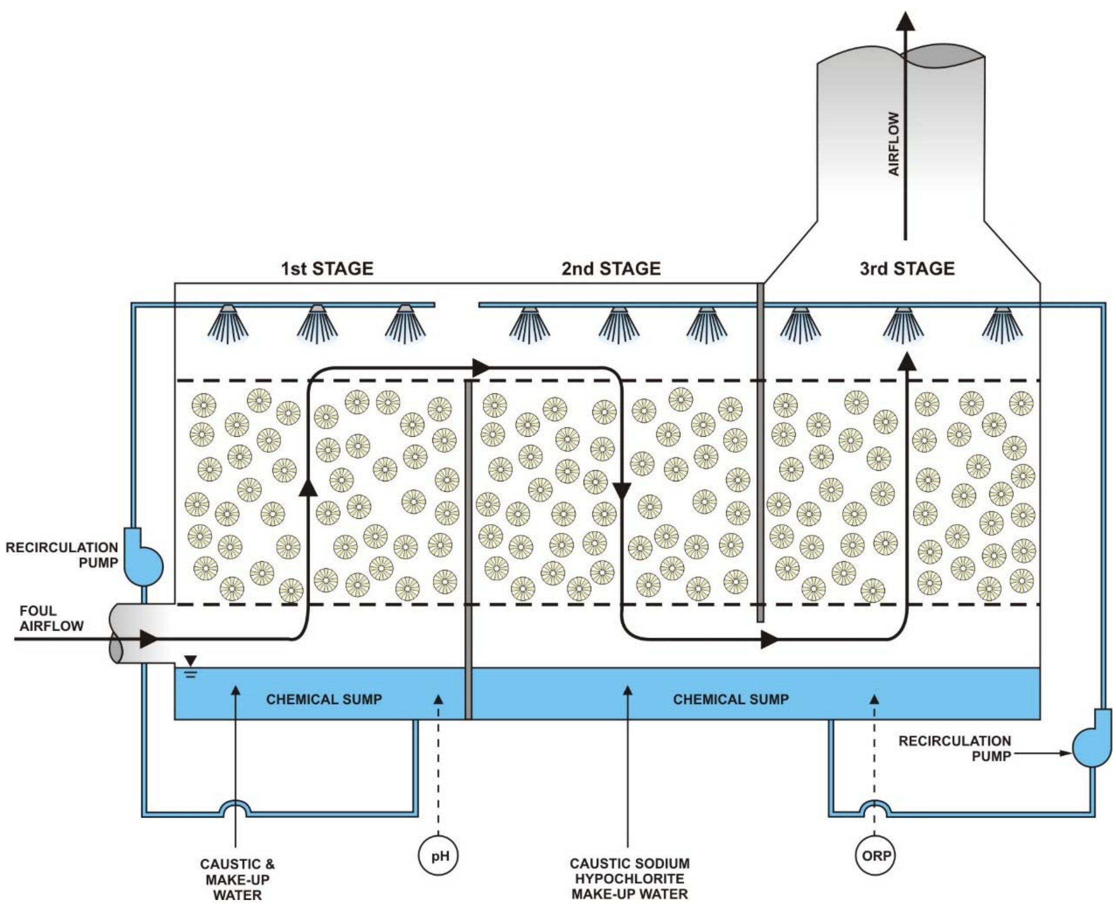


Figure 3-2: Multi-Stage Packed Bed Chemical Scrubber

For both single and multi-stage scrubbers, a portion of the scrubbing liquid is automatically wasted and make-up water is continuously added. Caustic feed is automatically controlled to maintain a set point pH in the scrubbing liquid, while sodium hypochlorite feed is automatically controlled to maintain a set point oxidation reduction potential (ORP) in the scrubbing liquid.

For the purpose of this memorandum, it was assumed a two-stage chemical scrubber would be utilized at the SDWRF for better odor removal.

3.2 Biofilters

Biofilters use a biological process to remove odorous compounds from the foul air. Two types of biofilters can be used: (1) built-in-place; or (2) modular. The maximum capacity of modular biofilters is typically limited, whereas the built-in-place type can be constructed as large as necessary, assuming that space is available.

Biofilters have the advantages of requiring less maintenance and less chemicals in comparison to chemical scrubbers. Some types of manufactured biofilters do have chemical addition to aid biological growth during periods of lower hydrogen sulfide concentration in the foul air stream treated. Typically, this is just a nutrient-rich solution to promote biological growth. Because odor reduction is accomplished through a biological process, conditions that promote the growth of odor-removing bacteria must be maintained. The bed material must be continually wetted and some source of trace nutrients must be available in order to achieve acceptable removal efficiencies.

The biofilter bed can be constructed of several different materials. Compost type material (organic media) is typically used, but inorganic and synthetic media are also available. Inorganic media resembles lava rocks, and has the necessary trace nutrients embedded in the media. Inorganic media has several significant advantages. The minimum empty bed retention time (EBRT) required for inorganic media is 20 to 40 seconds, depending on loading rates, whereas organic media requires a residence time of one minute or greater. The depth of inorganic media beds can be in excess of 5 feet, while organic bed depths are limited to 3 feet. Therefore, use of inorganic biofilter media results in significantly smaller bio-filter footprints, an important consideration when installing new odor control units at space-limited sites. Other advantages of inorganic media are: much longer life (10 years compared to 3 years), a long media warranty (10 years), and the ability to regenerate the media rather than having to replace it. For this study, the use of inorganic media has been assumed due to space constraints.

Modular biofilters are typically enclosed biofilters and have a more compact design than built-in-place type biofilters. Modular biofilters usually consist of a skid-mounted fiberglass enclosure that contains the biofilter media and a recirculation pump for make-up water and nutrient additive. The make-up water is sprayed over the media to create an environment in which sulfide reducing bacteria thrive. Nutrients may be added to the make-up water periodically to maintain the bacteria during lower hydrogen sulfide intervals if necessary. A schematic of a typical modular type biofilter is shown in **Figure 3-3**.

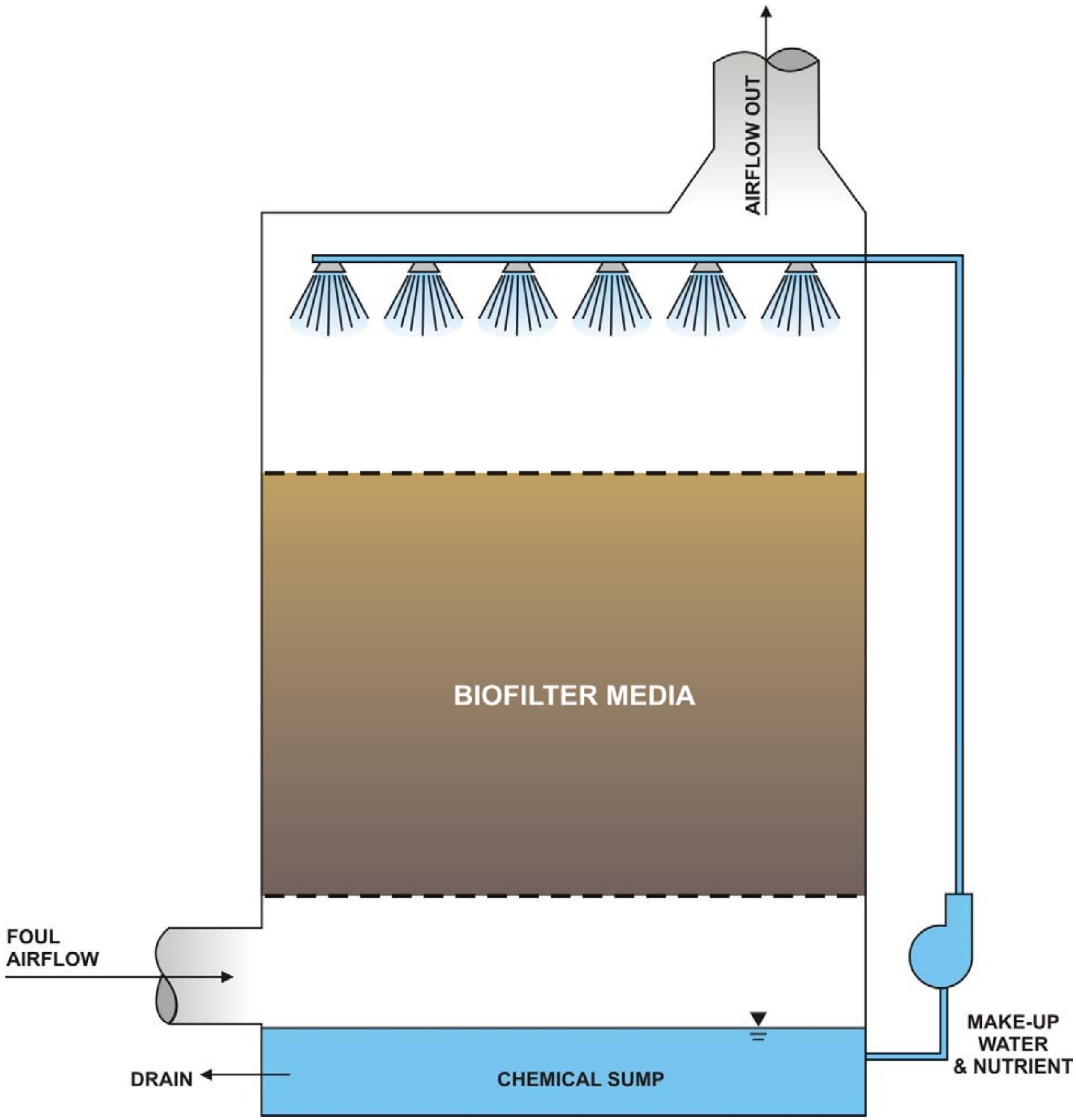


Figure 3-3: Modular Type Biofilter

One disadvantage of built-in-place type biofilters is the space that they require. A typical design will require 1 ft^2 for every 1 – 5 cubic feet per minute (cfm) of treated air. The area required to treat a large air flow can become relatively large. For the site plans shown in this memorandum, built-in-place biofilters are shown to represent the larger footprint required. Another disadvantage of biofilters is that they do not utilize a controlled process, hence, removal data can be inconsistent. In some cases, high removals have been reported, whereas in other cases, the removals have been poor. To protect against odor breakthrough in periods of biological upset, a carbon polishing step is recommended.

Biofilters are limited in the hydrogen sulfide concentrations they can treat. For hydrogen sulfide concentrations of 50 ppm and above, bio-trickling filter technology is recommended instead of biofilter.

3.3 Bio-trickling Filters

Bio-trickling filters are biological systems that are primarily designed to treat high hydrogen sulfide air streams (greater than 50 ppm average concentration). They are typically vertical, cylindrical vessels that resemble carbon scrubbers. Bio-trickling filters have a lower EBRT (10 to 30 seconds) than biofilters because they are used in applications with high hydrogen sulfide loads and do not have to get the exhaust streams as clean as other systems. For example, 95% removal of hydrogen sulfide at 300 ppm will still have an exhaust concentration of 15 ppm. The difference between a biofilter and a bio-trickling filters is that the system uses synthetic media and recirculates the water to maintain the biomass on the media. The synthetic media is designed so that it does not deteriorate under the highly acidic conditions.

Bio-trickling filters are very susceptible to biological upsets, particularly when concentrations in the air stream are low (less than 20 ppm). This is why they are much more effective in high hydrogen sulfide conditions. They also do not remove other reduced sulfur compounds, like methyl mercaptan or dimethyl sulfide, as well as biofilters do. Based on the sampling data, the preliminary treatment facilities at South Durham would be well suited for treatment with bio-trickling filters due to the higher concentrations of hydrogen sulfide. The life cycle analysis in this memorandum will assume biotrickling filters and carbon polishing units will be utilized at these locations. As with the biofilter, a carbon polishing unit is recommended to follow the bio-trickling filter to remove hydrogen sulfide during potential biological upsets and remove other reduced sulfur compounds..

3.4 Carbon Adsorption

Carbon adsorption scrubbers can be effective for odor control, with removal efficiencies for most odor-causing compounds found in wastewater treatment facilities of approximately 99%. However, there are several disadvantages associated with them. If the concentration of odor is high, the carbon will be consumed quickly, thereby requiring regeneration or replacement. For example, a carbon vessel with an EBRT of 5 seconds would require media replacement every six months if the average hydrogen sulfide concentration is 20 ppm. The replacement time would decrease to 1 month if the average hydrogen sulfide concentration is 100 ppm. Frequent replacement can cause disposal problems and result in higher operating costs.

Carbon adsorption scrubbers for this application would be installed as a polisher for biological treatment (biofilter or bio-trickling filter). A permanganate impregnated carbon would be used in the carbon polisher to remove other reduced sulfur compounds like methyl mercaptans. The biofilter would primarily be designed to remove hydrogen sulfide concentrations. The carbon polishers would also be capable of removing hydrogen sulfide if there was an upset in the biofilter's biology. **Figure 3-4** illustrates a built-in-place biofilter followed by carbon polishing scrubber; this system is currently in operation at the South Cary Water Reclamation Facility in Cary, North Carolina.

Figure 3-4: Built-in-Place Biofilter with Carbon Polishers. Location: South Cary Water Reclamation Facility in Cary, North Carolina

4.0 South Durham Odor Control Alternatives

The chemical Odor Scrubber 1 at the SDWRF currently serves the GBT/BFP Building and the sludge blend tanks with a total capacity of 28,250 cfm. The sludge blend tanks, which comprise 4,250 cfm of the air flow, are no longer in service. The remaining 24,000 cfm treated at Odor Scrubber 1 comes from the GBT/BFP Building. The H_2S monitoring conducted in the GBT/BFP Building recorded hydrogen sulfide levels below 1 ppm for the week it was installed, indicating it is not a significant source of odor. Based on the hydrogen sulfide monitoring results, it is recommended to ventilate the GBT/BFP building to atmosphere in lieu of rehabilitating/replacing the scrubber for odor control. It is important to maintain ventilation to prevent corrosion and to maintain safe working conditions within the building. While specific dispersion modeling was not conducted for the SDWRF GBT/BFP Building, the sampling results and air flow rates are very similar to the Solids Handling Building at the NDWRF Plant A. The dispersion model completed for the NDWRF Solids Handling Building indicates ventilating the building air from a discharge on the roof would dilute to an acceptable concentration (D/T = 10) within 250 ft from the building. The continued use of the existing odor control fan is a feasible no-cost option for this area.

An option that should be considered is to fit the unit with an industrial exhaust system in lieu of discharging to the atmosphere directly from the odor scrubber. The Tri-Stack system shown in **Figure 3-5** is a fume exhaust system that Hazen and Sawyer has used on several other projects. The Tri-Stack fan essentially dilutes the exhaust air from the building with clean air from the outside of the building. As a result, the total exhausted stream has a more dilute concentration of potential odor causing compounds.

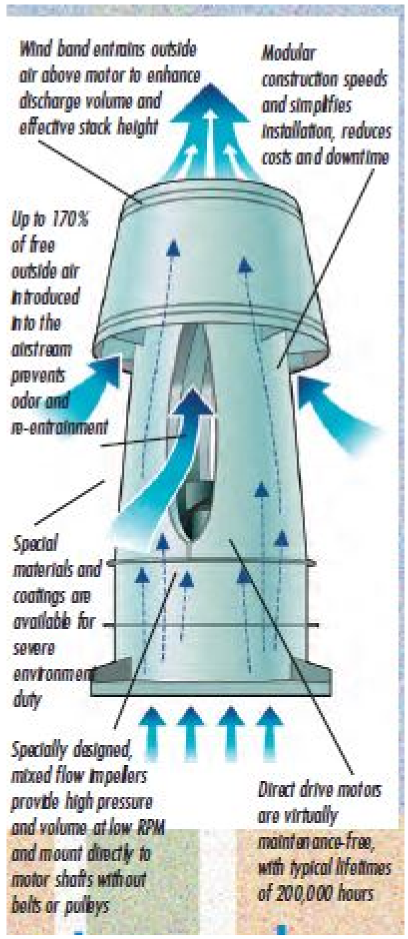


Figure 3-5. Tri-Stack Discharge Stack Illustration From Strobic Air Fan

The proposed treated airflow at the SDWRF would be 10,000 cfm based on the airflows from each process area and the current design drawings. The results of the sampling that was conducted indicate the average hydrogen sulfide loading to this odor control system would be approximately 50 ppm average with a peak of 100 ppm. **Table 3-1** summarizes proposed airflows to the modified scrubber serving Preliminary/Primary treatment processes at the SDWRF. Based on the anticipated loading, two odor control alternatives were evaluated: two-stage chemical scrubber and biological (bio-trickling filter) followed by carbon polishing step.

Table 4-1: Proposed SDWRF Preliminary/Primary Process Odor Control Airflows		
Process Area	**Airflow (cfm)**	**Number of Air Changes per hour**
Primary Settling Tanks	4,800	10+
Primary Effluent Channel	1,300	12
Scum Pump Wet Well	50	10+
Scum Concentrator Building	1,800	11+
New Preliminary Treatment Facility (covered areas only)	1,800	12
Total Airflow	**10,000**	

In the new PTF, the areas under the covered channels would be scrubbed at a rate of 12 air changes per hour while the rest of the building is ventilated to atmosphere at a rate of 12 air changes per hour.

The results from sampling and monitoring suggest hydrogen sulfide loading to the 3,000 cfm scrubber serving the influent manhole and pump station wet well would be approximately 10 ppm average with a peak of 75 ppm. Based on this loading, two odor control alternatives were evaluated: two-stage chemical scrubbing and biological (biofilter) followed by carbon polishing step.

5.0 Life Cycle Costs

Life cycle costs were developed for the SDWRF using both chemical scrubbers and biological treatment with carbon polishing. The life cycle cost analysis is based on the following assumptions:

- 20-year planning period
- Interest Rate: 3%
- Power costs, $0.06/kW/hr
- 25% Sodium Hydroxide, $0.75/gal
- 12.5% Sodium Hypochlorite, $0.75/gal
- Water cost, $0.004/gal
- Media Life
    - Biofilter: 10 years
    - Bio-Trickling Filter: 15 years
    - Carbon Scrubber: 2 years

All costs are shown in 2015 dollars. Capital costs are inclusive of all contractor overhead and profit, contingencies, etc. Capital, operating and lifecycle costs for the 10,000 cfm odor control serving the Preliminary / Primary Treatment and the 3,000 cfm unit serving the influent manhole and pump station wet well are presented in **Tables 4-1** and **4-2**, respectively.

Table 4-1: SDWRF Preliminary and Primary Treatment 10,000 cfm Comparison			
	Two-Stage Chemical Scrubber	**Bio-trickling Filter**	**Carbon Polish**
Operating Labor	$37,440	$9,360	$6,240
Electrical	$16,006	$16,006	$0
Chemicals	$32,078	$0	$0
Water	$33,638	$2,190	$0
Carbon/Media Replacement	$0	$2,667	$21,206
Total Operating	$119,000	$58,000	
Capital Cost	$1,427,000	$793,000	
Life Cycle Cost	$3,197,000	$1,656,000	

Table 4-2: SDWRF Influent Pump Station 3,000 cfm Comparison			
	Two-Stage Chemical Scrubber	**Biofilter**	**Carbon Polish**
Operating Labor	$37,440	$9,360	$6,240
Electrical	$9,115	$3,529	$0
Chemicals	$10,033	$0	$0
Water	$16,819	$730	$0
Carbon/Media Replacement	$0	$2,505	$6,786
Total Operating	$73,000	$29,000	
Capital Cost	$1,015,000	$545,000	
Life Cycle Cost	$2,101,000	$976,000	

The lifecycle costs for biological odor control followed by carbon polishing are lower than two-stage chemical scrubbing for both the 10,000cfm unit serving the Preliminary/Primary processes and the 3,000 cfm unit serving the influent manhole and pump station wet well. The amount of chemicals consumed make the operational costs for the chemical scrubber option significantly higher than the biological option, offsetting any initial differences in installed capital cost.

On a 20-year life cycle basis, the recommended biological treatment alternatives are less expensive than rehabilitation of the existing chemical scrubbers explored during the PER phase, as shown in **Table 4-3**.

Table 4-3: Recommended Life-Cycle Cost		
	Biological Treatment with Carbon Polishing	**PER Rehabilitation**
Capital	$1,738,000	$1,446,000
Annual Operating	$87,000	$192,000
Life Cycle Cost	$2,632,000	$4,302,480

6.0 Recommendations

Based on the life cycle cost analysis presented above, the following odor control improvements are recommended at the SDWRF:

- Ventilate the GBT/BFP building to atmosphere and add a fume exhaust system for increased dilution, abandon Odor Scrubber 1.
- Install a bio-trickling filter and carbon scrubber as part of Phase 1 to scrub the proposed Preliminary Treatment Facility, the scum handling building, and the primary clarifier weirs.
- Install a biofilter and carbon scrubber at the Influent Pump Station.
- Replace dampers due to significant corrosion observed.
- Replace all buried foul air FRP ductwork with HDPE.

The total capital costs for the recommended alternatives are presented in **Table 5-1** below.

Table 5-1: Recommended Alternative Costs	
Item	**Cost**
Influent PS	$545,000
Preliminary Treatment	$793,000
Ductwork and Dampers	$400,000
Total Capital (2015)	**$1,738,000**